

**WAVE ENERGY DEVICE**

The Invention relates to a wave energy device.

- 5 Wave motion in bodies of water has long been recognised as a source of renewable energy. The invention aims to provide a device for exploiting this energy resource.

According to one aspect, the invention provides a wave energy device in the form of heave-resistant vessel comprising two or more flow paths into which water can  
10 be urged by wave action and an energy extractor in fluid communication with said path(s) and arranged to extract energy from air movements in said path(s) caused by said wave action.

According to another aspect of the invention, there is provided a wave energy  
15 device in the form of a heave-resistant vessel comprising one or more flow paths into which water can be urged by wave action and an energy extractor in fluid communication with said path(s) and arranged to extract energy from air movements in said path(s) caused by said wave action.

20 In a preferred embodiment, there is a plurality of flow paths, as least some of which have different lengths. In this way, flow paths can have different frequencies in order to allow the device to extract energy from waves of different periodicity in an efficient manner.

The or each flow path may be in communication with the atmosphere, at some point beyond the energy extractor.

In one embodiment, there is a plurality of flow paths comprised of a group of  
5 chambers. The chambers may be uniform or dissimilar. The chambers may be polygonal, rounded or indeed circular in cross-section.

In some embodiments, the wave energy entrance to at least one of the flow paths is shaped to enhance the energy extraction process. Preferably, this shaping is applied  
10 to the part of the flow path that is adjacent to the wave entrance of the flow path and takes the form of a smooth flaring of the flow path as it extends towards the wave entrance. Such shaping can reduce the turbulence created in water exchanged with the flow path under wave action.

15 In certain embodiments, two or more flow paths may combine before communicating with the energy extractor.

The heave-resistance of the vessel can be achieved in various ways. For example, the vessel may be tethered under tension to, say, the sea bed. If necessary or  
20 desired, the tethering system can have sufficient elasticity to allow the vessel to rise and fall with tidal activity. As one alternative to the use of tethers, or possibly in addition to the use of tethers if necessary, the heave-resistance of the vessels may be achieved or aided by the design of the vessel. This is to say, the footprint which the vessel presents to the water or, to state it another way, the cross-

sectional area occupied by the vessel in plane of the water surface may be kept low in order to reduce an increase in buoyancy of the vessel due to water rising around the vessel from wave action. If necessary or desired, it is also possible to fit the vessel with a floatation aid.

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Preferably, said heave resistance is provided by a positive buoyancy and tethering arrangement.

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The energy extractor is preferably turbine-based for converting the energy in the air movements into electrical energy. However, the energy extractor may be arranged to perform other types of energy extraction. For example, the energy extractor may simply convert the air movements into mechanical energy for the use by some other system or the energy extractor could be arranged to convert the energy in the air movements into hydraulic energy.

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Preferably, there is a plurality of flow paths, at least some of which have different flow cross-sectional areas.

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Preferably, there is a plurality of flow paths, at least some of which have different internal flow volumes.

By the way of example only, certain embodiments of the invention will now be described with reference to the accompanying figures in which:

Figure 1 is a side elevation of a wave energy device;

Figure 2 is a simplified view of the device of Figure 1 taken from the sea bed;

Figure 3 illustrates the thickening of the chamber walls in the device of Figure 1;

Figure 4 is a schematic diagram illustrating the principle of operation of the device of Figure 1; and

Figure 5 illustrates an alternative deployment of the device shown in Figure 1.

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Figure 1 illustrates a wave energy device 10 deployed in the sea and anchored to the sea bed 12 by tethers 14. The wave energy device 10 is arranged to float such that part of its structure protrudes from the surface of the water. In Figure 1, the mean sea level is indicated 16. Wave crests will protrude above the mean sea level 16 and wave troughs will dip below this level.

The main structural element of the wave energy device 10 is a group of elongated chambers that extend in parallel to one another and whose walls are structurally linked or common and thus lend rigidity to the wave energy device 10. The chambers extend vertically from the vicinity of a turbine 18 located above the water surface to differing depths below the water surface. The upper ends of the chambers are ducted into the turbine 18 and the lower ends of the chambers extend, by differing amounts, from a buoyancy jacket 20 which shrouds the group

of chambers. The lower ends of the chambers protruding from the buoyancy jacket 20 are generally indicated 22 in Figure 1.

The lower ends of the chambers are open to the water. The upper ends of the  
5 chambers lead into the ducting which places the chambers in fluid communication with the turbine 18. The turbine 18 opens into the atmosphere and places the ducting, and hence the chambers, in fluid communication with the atmosphere.

In the wave energy device 10 shown in Figure 1, there are six chambers in the  
10 group. The chambers, when viewed from below towards their open ends, appear as equal segments of a hexagon, as shown in Figure 2. The six chambers have different lengths. Chamber 24 is the shortest and each successive chamber in the clockwise direction is longer than the preceding one, the sequence terminating with chamber 26.

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The wave energy device 10 is designed such that its overall density would cause it to float relative to the mean sea level 16 in the position shown in Figure 1. Moreover, the wave energy device 10 is designed so that the effect of wave action upon its buoyancy is minimised. Essentially, the advent of a wave crest at the side  
20 of the wave energy device is a temporary increase in the water level in the vicinity of the device 10. This increase produces a temporary submersion of an additional part of the volume of the device 10, leading to an additional upward force on the device 10. The device 10 can be designed such that the amount of additional volume that is submerged by wave action is reduced to an extent sufficient to make

the aforementioned additional upward force negligible relative to the weight of the device 10, therefore producing the result that the wave action has little effect on absolute vertical position of the wave energy device 10.

5 By way of illustration of this principle, reference can be made to Figure 3 in which the walls of the cylindrical chambers have been thickened (without changing the chamber's external cross-sectional dimensions). In Figures 2 and 3, the shaded, i.e. solid, areas represent the cross-sectional area of the chamber walls in the plane of the mean water level 16. The thicker walls in the embodiment of Figure 3 provide  
10 for increased buoyancy of the device 10. It will be apparent that a temporary increase in water level due to the presence of a wave crest at the device 10 would lead to a significantly larger increase in water displacement in the case of a device having a greater cross-sectional area in the plane of the mean water level leading to a greater upward force in that case, that is to say the upward force is dependent  
15 upon the overall flow cross-sectional area of the successive chambers at the plane of the mean water level.

In the embodiments of Figures 2 and 3 the cross-sectional areas of the successive chambers are substantially the same. However, in an alternative embodiment the  
20 flow cross-sectional area of the chambers may be different. For example, the flow cross-sectional of one or more of the chambers may be lesser or greater than the remainder. In different embodiments all the chambers may have different flow cross-sectional areas. As described above, the wave energy device 10 is designed to heave (i.e. move vertically) only minimally in response to wave action.

Accordingly, as a wave passes through the device 10, the water level will rise and fall in the chambers. As the water level rises in any given chamber, air will be pushed out of the chamber, through the ducting and through the turbine into the atmosphere. When the water level falls in any given chamber, air will be drawn  
5 down into the chamber from the external atmosphere via the turbine 18 and the ducting. Therefore, the passage of waves through the device 10 leads to an exchange of air through the turbine 18. Figure 4 provides a schematic illustration of this process.

10 In Figure 4, only those elements of the wave energy device 10 that are necessary for understanding the passage of the air flow through the turbine are shown. For example, in Figure 4, only one chamber, 26, is shown and the ducting between the chamber and the turbine 18 is omitted for the sake of clarity. The turbine includes a fan with a large number of vanes. In Figure 4, the axis of rotation of this fan is  
15 indicated by the dashed line and the tips of the vane on the half of the fan's circumference that faces towards the reader are indicated by the row of curved lines, of which 30 is an example.

As a wave crest approaches the device 10, the water level 32 within chamber 26  
20 rises causing air to be expelled from the chamber 26 through the turbine 18 in the direction indicated by the arrow A. This causes the fan to rotate in the sense in which the vane tips shown in Figure 4, such as 30, move from right to left. When the crest of the wave has passed by, the water level 32 within the chamber 26 drops, reducing the air pressure in the space above the water in chamber 26,

causing air to be drawn into chamber 26 through the turbine in the direction indicated by arrow B. Although this air flow is in the opposite direction to before, the fan will rotate in the same sense as before because of special shaping applied to its vanes. The chambers vent independently into the turbine 18. Thus, it is possible  
5 that one chamber could be driving the turbine 18 by drawing air down into the device whilst, at the same time, another chamber is expelling air through the turbine. However, it is possible that some chambers join or merge so that they act on the turbine in unison. The fan of the turbine 18 is mechanically coupled to a generator so that the rotational energy of the fan can be converted into electricity.

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It will be apparent that the chamber 26 will resonate with a water wave of particular wavelength of period. The precise wavelength that will resonate with the chamber 26 depends upon the length of the chamber. When the chamber 26 is in resonance, the energy extractor from the chamber 26 by the turbine 18 will be at a  
15 maximum. However, water waves will, in practice, contain a spectrum of continuously varying wavelengths. To cater for this, the chambers of the wave energy device 10 each have a different length as described earlier. The provision of various chamber lengths increase the probability that at least some part of the wave energy device 10 will be operating under resonant conditions at any given time.

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Figure 5 shows an alternative way of deploying the wave energy device 10. In Figure 5, the wave energy device 10 is provided with positive buoyancy and it is restrained by taut tethers 14a which hold the device 10 in the position relative to the mean water level 16 that is shown in Figure 5. The tethers 14a prevent heave



motion of the wave energy device 10 and wave action causes the water level to rise and fall in the chambers 26 as in the deployment shown in Figure 1. The tethers 14a are, to a certain extent, elastic so as to accommodate any rise and fall of the mean water level 16 due to, for example, tidal action.